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INDUCED MANDEL'SHTAM-BRILLOUIN SCATTERING IN GASES

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We report in this letter on induced Mandel'shtam-Brillouin scattering (IMBS) observed by us in several compressed gases 1).

No discrete Mandel'shtam-Brillouin components (MBC) were observed in the only experimental investigation of the Rayleigh lines in thermal scattering of light in hydrogen at 100 atm, in nitrogen and oxygen at 80 atm, and in carbon dioxide at 50 atm [4].

In [5,6] it was shown, on the basis of a classical calculation and data on sound absorption in gases, that under the experimental conditions of [4] the discrete fine-structure components should be observed in all cases. The conditions for the existence of discrete MBC are determined by the inequality [6]

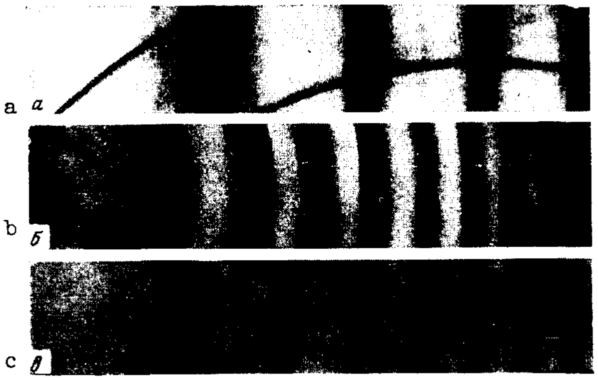
$$\alpha\Lambda \ll 1.$$

As shown by calculation [5,6], for gases $\alpha\Lambda = A(\bar{l}/\Lambda)$ (α, Λ, and $\bar{l}$ are the amplitude coefficient of sound absorption, the hypersound wavelength, and the mean free path of the molecule, respectively, and A is a constant, ≈25 for a diatomic gas).

At atmospheric pressure ($\bar{l} \sim 10^{-5}$, $\Lambda \sim 3 \times 10^{-5}$) there can be no discrete fine structure in thermal scattering of light ($\alpha\Lambda > 1$), but $\alpha\Lambda < 1$ already at 20 - 30 atm and the fine structure should be observable.

The disparity between the experiment [4] and the deduction of the theory [5,6] has remained unexplained until recently.

If the deductions of the theory are correct, then in compressed gases (P > 20 atm) we should observe a discrete fine structure of the Rayleigh line and, consequently, IMBS should be observable in principle. Whether it will be observed in reality depends on the magnitude of its threshold and on the experimental capabilities. When the condition $\bar{l} \ll \Lambda$ is satisfied, the expression for the threshold of IMBS in gases coincides formally with the expression for the threshold in liquids [6]. However, the magnitude of the threshold in gases at pressures



Induced Mandel'shtam-Brillouin scattering spectra in compressed gases

a - in hydrogen (p = 95 atm), Fabry-Perot interferometer dispersion range 1 cm^{-1}; b - in oxygen (p = 150 atm); c - in nitrogen (p = 125 atm). Interferometer dispersion 0.33 cm^{-1} for oxygen and nitrogen.

100 atm is 10^3 - 10^4 times larger than in liquids.

IMBS in compressed gases was observed with the installation described by us earlier [7], the laser light output power being approximately 250 MW.

The phenomenon was observed in nitrogen at 100 and 125 atm, in oxygen at 75, 100, and 150 atm, and in hydrogen at 95 atm.

The IMBS spectrum showed four Stokes components in nitrogen, four Stokes components and sometimes a weak anti-Stokes component in oxygen, and two Stokes components in hydrogen (see the figure).

No IMBS was observed in helium at 140 atm, as was to be expected, since $\alpha\Lambda > 1$ for helium under the conditions of our experiment (see the table).

	P atm	n	f x 10^{-9} cps	Λ x 10^5 cm	$\alpha\Lambda$	Measured in present work		v_{adiab} m/sec	$v_{isotherm}$ m/sec
						$\Delta\nu$ x 10^2 cm^{-1}	hypersound speed, m/sec		
N_2	125	1.035	0.84	3.3	0.06	2.8 ± 0.1	280 ± 10	352	297
O_2	150	1.038	0.99	3.3	0.06	3.3 ± 0.3	330 ± 30	331	280
H_2	95	1.012	3.3	3.4	0.14	11 ± 1	1130 ± 100	1334	1127
He	140	1.005	2.6 (calc.)	3.5 (calc.)	1.7	-	-	1008	783

The velocity of the hypersound was determined for all three cases from the positions of the discrete MBC 2). The table lists the determined values of the hypersound velocity and, for comparison, the adiabatic and isothermal sound velocities as well as other characteristics of the medium and of the experimental conditions. It follows from the results that the value of the speed of hypersound for nitrogen and hydrogen is lower than the adiabatic speed of sound in these media, although it would be expected that the possible heating in the volume where the IMBS takes place should make the hypersound speed noticeably larger than its adiabatic value.

It is possible that the observed decrease in speed is due to the fact that the IMBS is produced not in a neutral gas, but in a nonequilibrium plasma, which is produced in the focused beam of the giant laser pulse.

The frequency at which the sound becomes isothermal can drop in the plasma as a result of the increase in the thermal conductivity, and the sound will become isothermal. Whether the observed decrease in speed is due to one factor or the other will be clarified in the future.

The speed of hypersound in oxygen is such that its average is close to the adiabatic value, but detailed measurements give for the shift of the first Stokes component a value smaller than for the second, and for the second a value smaller than the third.

The speed of hypersound in oxygen, calculated from the first component, is close to its isothermal value.

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1) IMBS was observed earlier in crystals [1], liquids [2,3], and amorphous solids [3].

2) In scattered light the exciting line consists of three discrete modes having strongly differing intensities. All three modes lie within a band of 0.02 cm^{-1}. The speed was calculated by reckoning from the most intense mode.

DISPERSION OF SOUND IN SUPERFLUID HELIUM

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At low frequencies ($\omega\tau \ll 1$, ω = frequency of sound, τ = some characteristic times) the absorption of sound is investigated with the aid of the hydrodynamic equations [1]. The question of sound propagation at not too low frequencies ($\omega\tau \gtrsim 1$) is considered with the aid of the kinetic equations. These, together with the equations for the continuity of the mass and of the superfluid liquid, constitute a complete system of equations describing the propagation of sound in helium II.

This question is dealt with in [2]. The favorable situation with respect to establishment of energy equilibrium of the excitations in the gas leads essentially to an exact solution of the problem. The point is that the effective cross section for roton-roton scattering is